Code-based Cryptography

Side-Channel Attacks

Fraunhofer Workshop Series 01 – Post-Quantum Cryptography in Practice

Speaker: Dr. Bernhard Jungk

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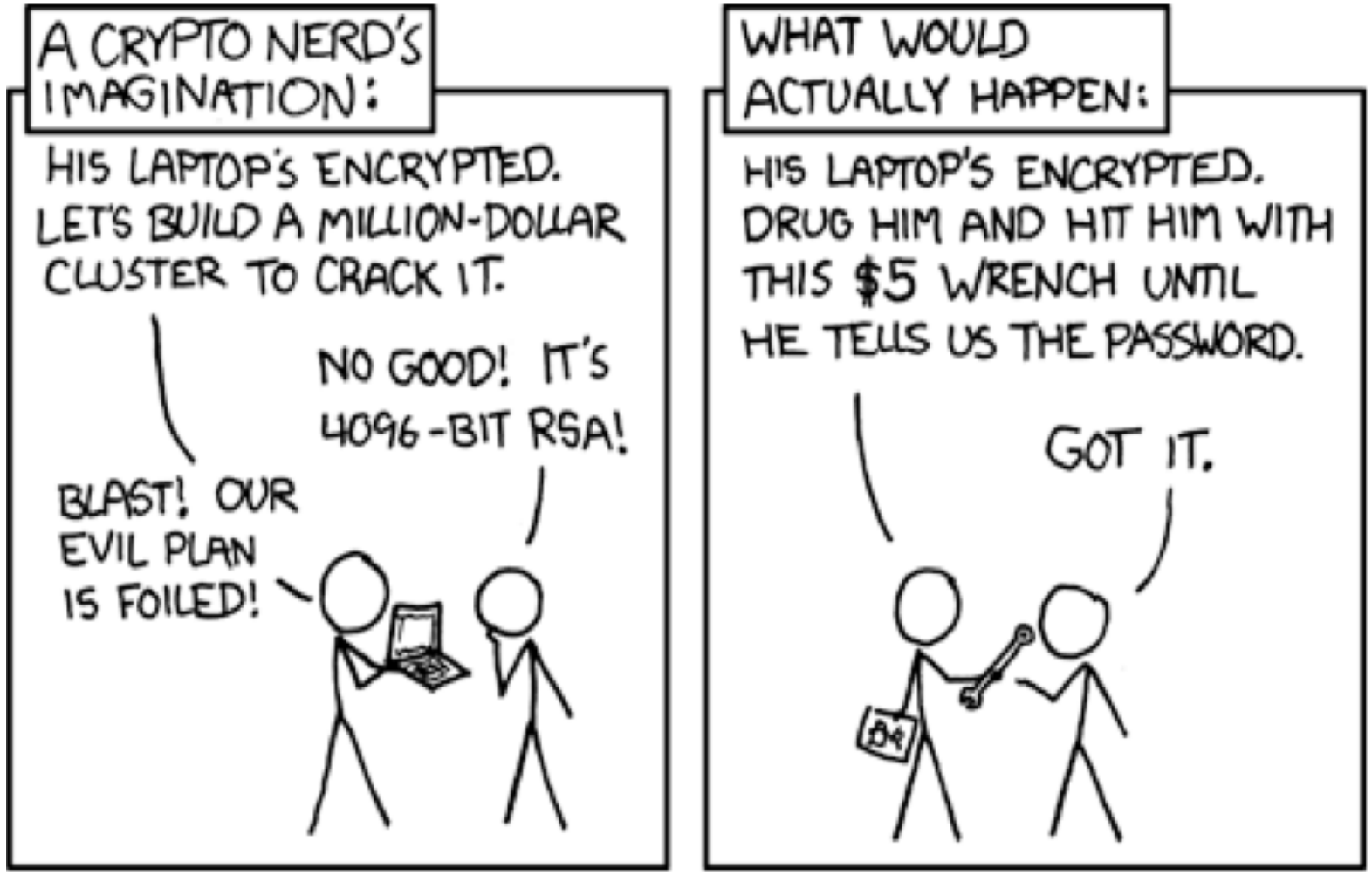
Introduction to Side Channel Attacks


A CRYPTO NERD'S IMAGINATION:
HIS LAPTOP'S ENCRYPTED. LET'S BUILD A MILLION-DOLLAR CLUSTER TO CRACK IT.
NO GOOD! IT'S 4096-BIT RSA!
BLAST! OUR EVIL PLAN IS FOILED!
WHAT WOULD ACTUALLY HAPPEN:
HIS LAPTOP'S ENCRYPTED. DRUG HIM AND HIT HIM WITH THIS $5 WRENCH UNTIL HE TELLS US THE PASSWORD.
GOT IT.

Side-Channel Attacks

Background on Side-Channels

Timing Side-Channels

- Remote key extraction, many examples:
  - » 2005 "Cache-Timing Attack on AES", Bernstein
  - » 2017 "A Microarchitectural Side Channel Attack on Several Real-World Applications of Curve25519", Genkin et al.
- Meltdown and Spectre 
  - » Most processors vulnerable to one of the problem
  - » Extraction of kernel space memory possible
  - » Architectural problem of the processor designs
- Very high impact on most systems with remote interfaces (from smartcards to servers)

Side-Channel Attacks

Background on Side-Channels

Power/EM Side-Channel Attacks

- First published by Kocher in 1999
- Many variants
  - » Simple power analysis → Direct interpretation of traces
  - » Differential/correlation power analysis → Statistical modelling
  - » Template attacks → Profiling of device
  - » Machine-learning based approaches → Advanced profiling of device
- Countermeasures are costly
  - » Masking removes some leakages completely in theory
  - » Hiding reduces the signal to noise ratio
- High impact on embedded systems and smartcards

Side-Channel Attacks

Power and EM analysis – A short introduction

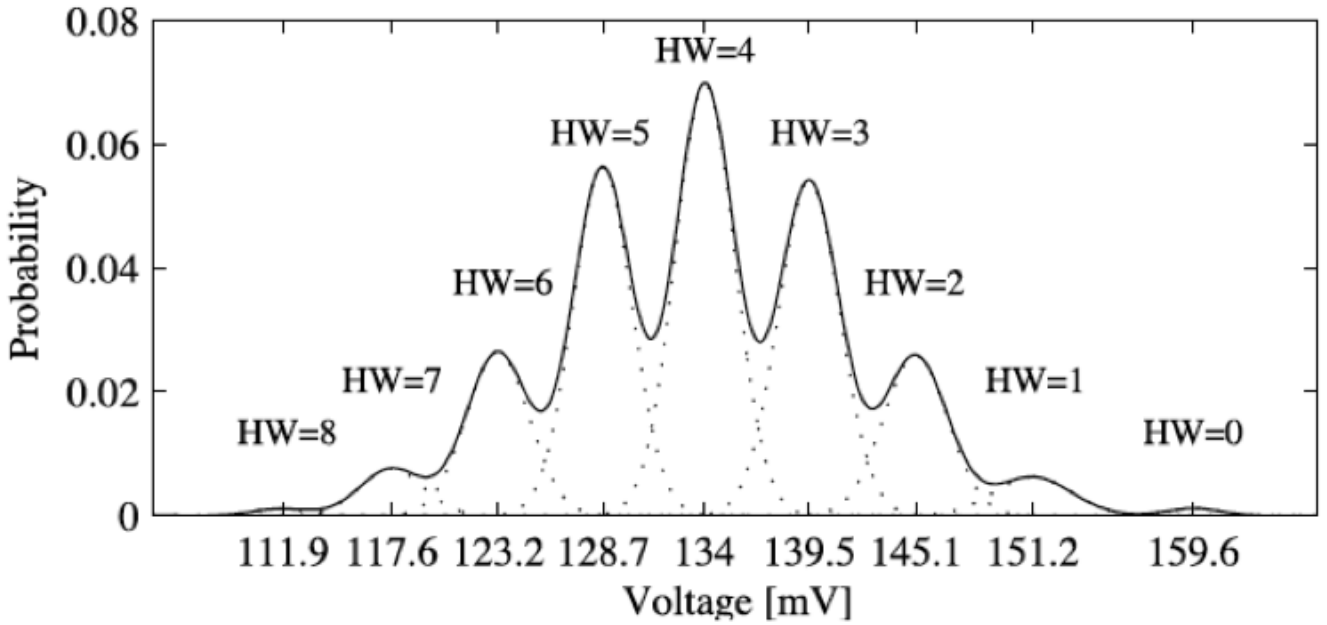
Energy consumption changes:

- Depending on the algorithm:
  - Different operations consume a different amount of energy.
- Depending on the input data:
  - In traditional CMOS switching consumes the highest amount of energy
  - Switching from 0 to 1 (or 1 to 0) consumes more energy than the 0 to 0 (or 1 to 1) transitions.

Side-Channel Attacks

Power and EM analysis – A short introduction

Statistical Modelling of Leakage



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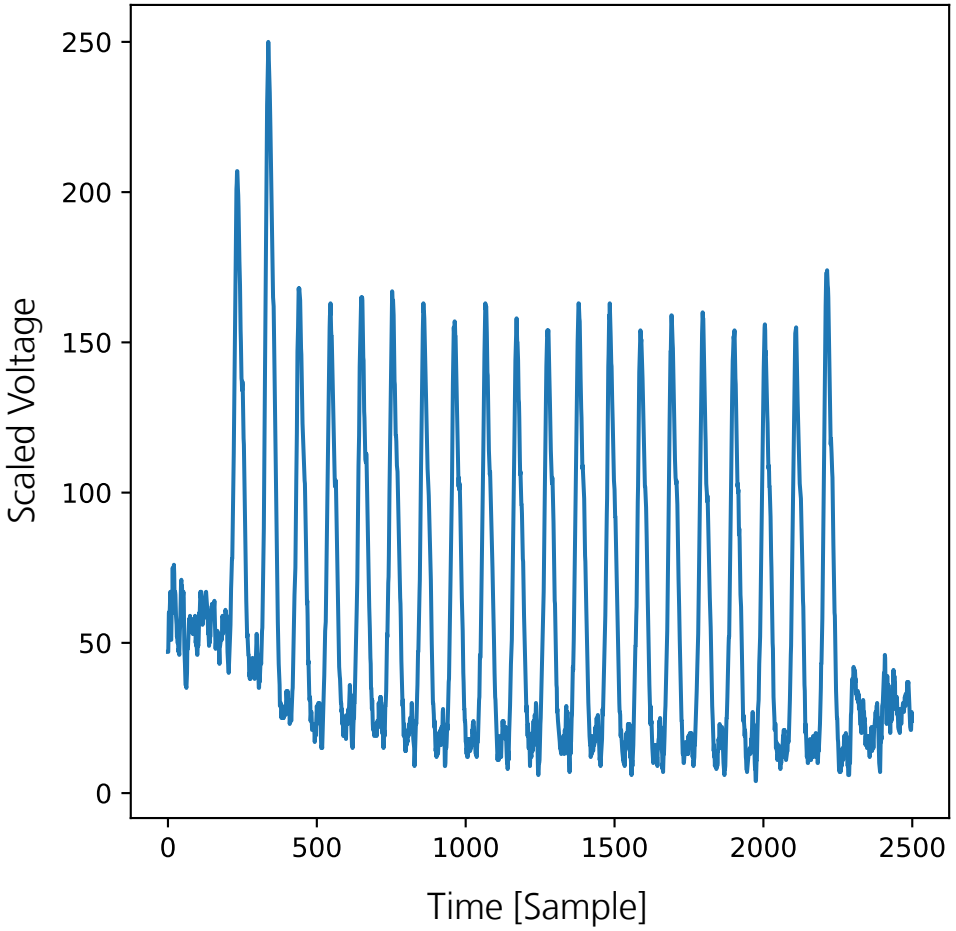
Side-Channel Attacks

Power and EM analysis – A short introduction



FPGA Implementation of ChaCha20:

- 20 clearly identifiable rounds
- Measured power consumption changes in each round:
  - Internal data
  - Measurement noise

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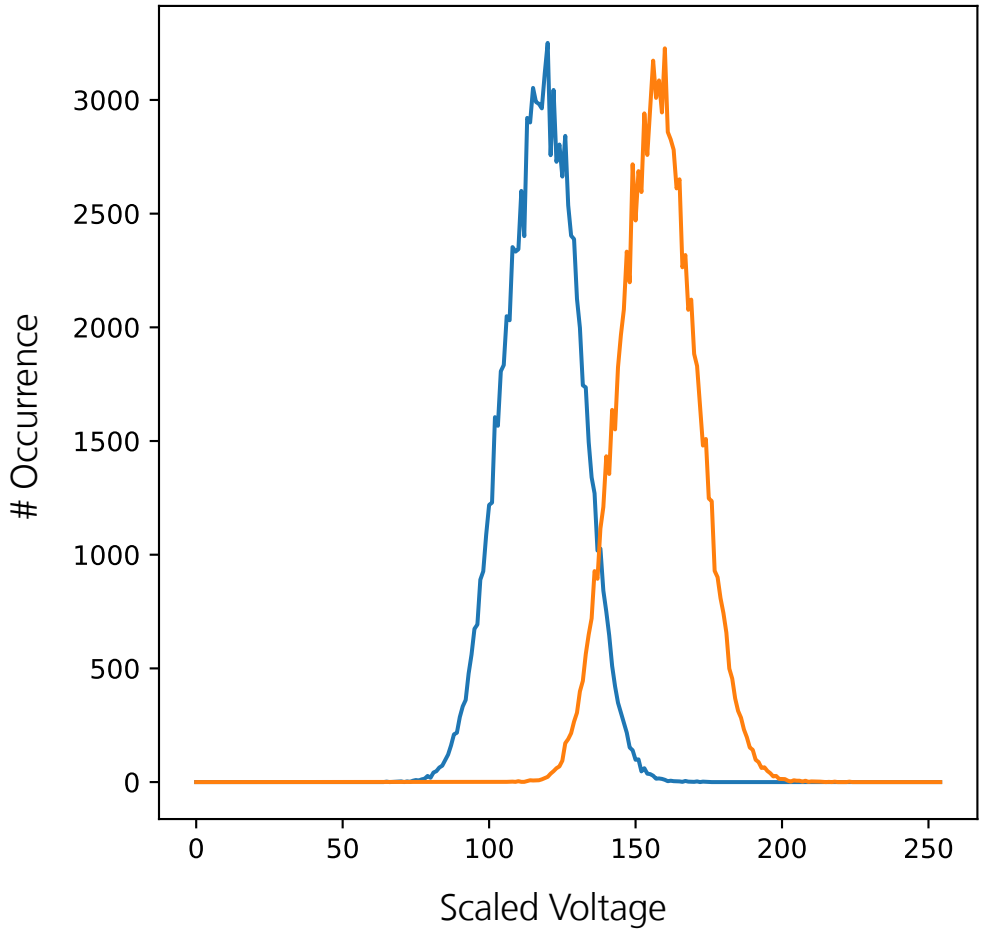
Side-Channel Attacks

Power and EM analysis – Modular Addition



Protected FPGA Implementation of Modular Addition:

- PRNG for mask generation was deactivated
- Histogram of a leaking point of interest
- Different inputs clearly identifiable in histograms

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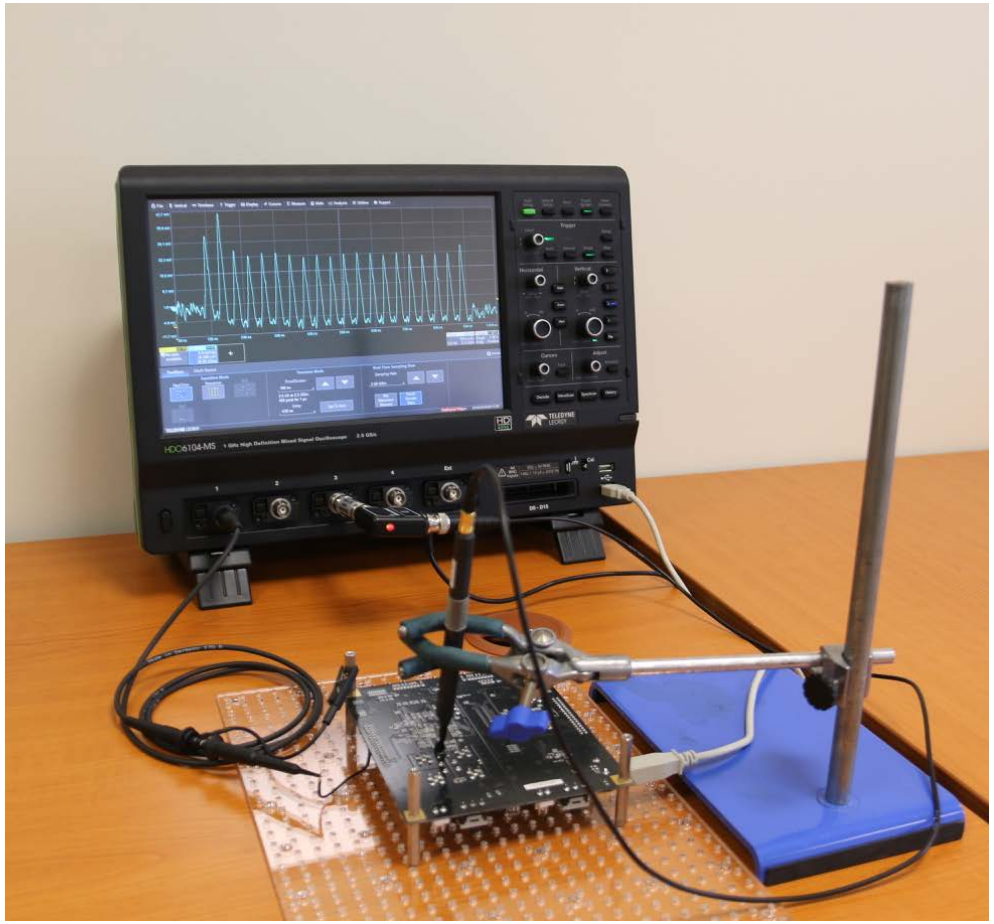
Side-Channel Attacks

Power and EM analysis – General Approach for Profiled Attack



Our setup for this attack:

Oscilloscope: Lecroy HDO6104-MS

Target: SASEBO GII

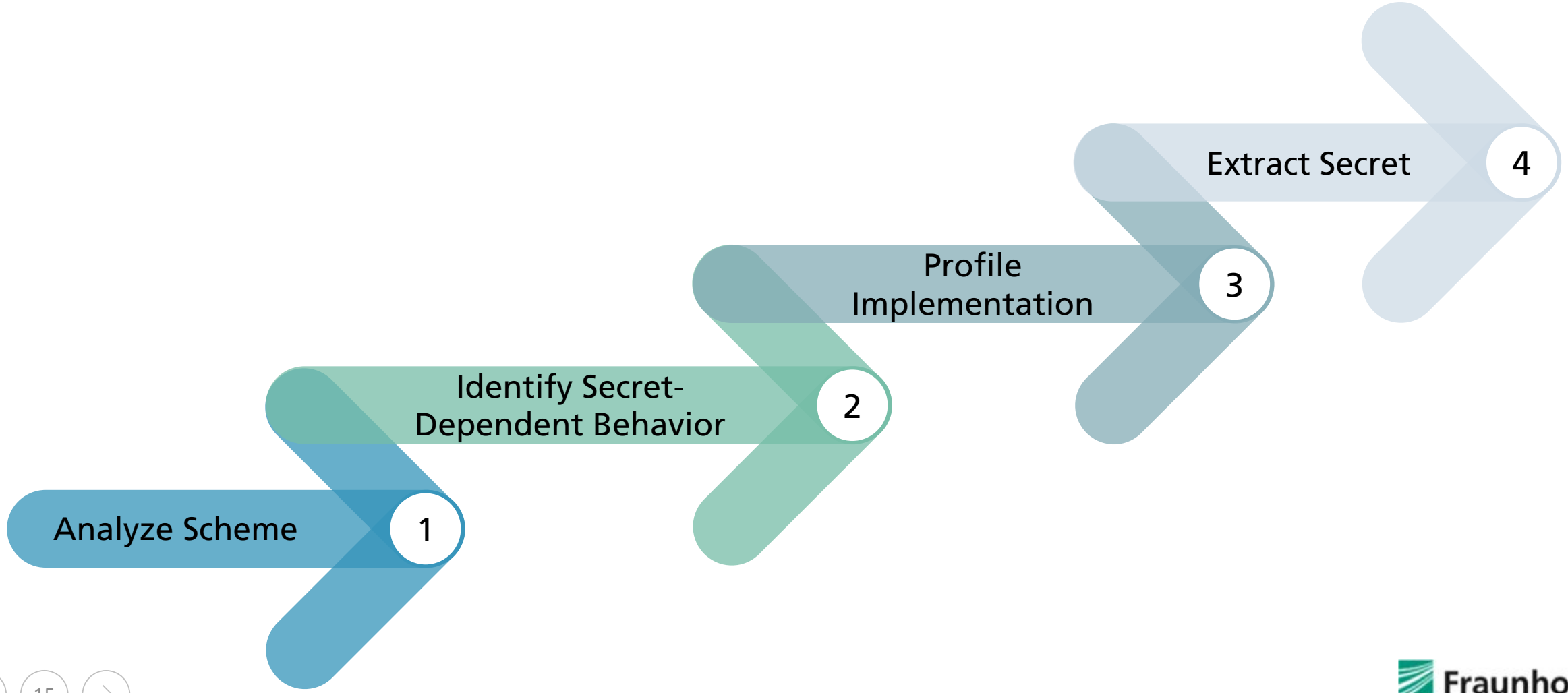
(Side-Channel Evaluation Board with Xilinx Virtex-5 FPGA)

Probe: Langer RF-U 5-2

Side Channel Attacks on the Niederreiter Cryptosystem

Attack Strategy

Niederreiter Cryptosystem



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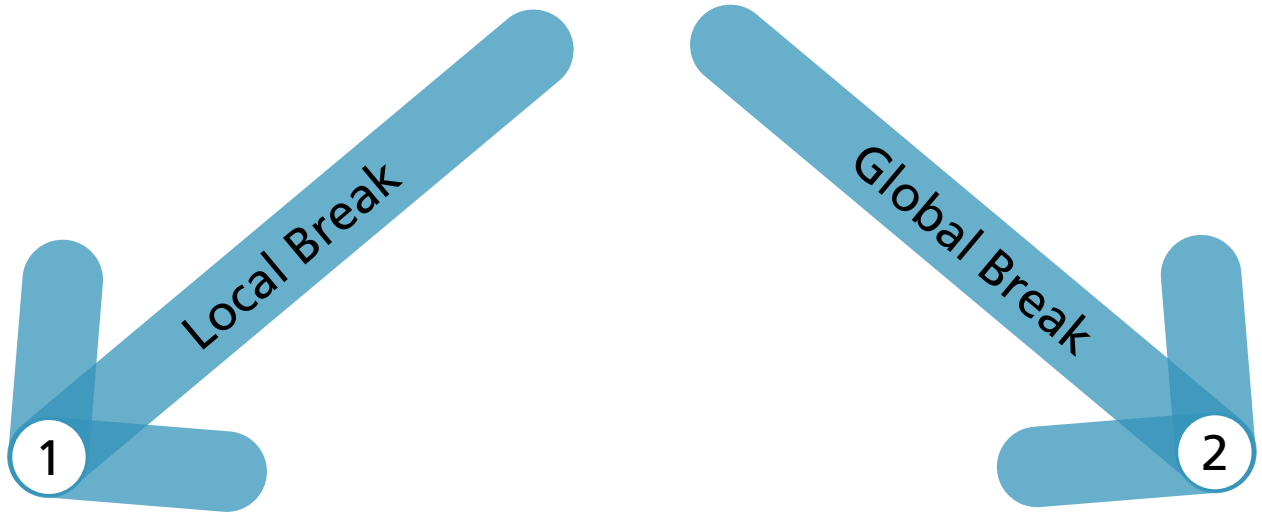
Application to Code-Based Cryptography

Niederreiter Cryptosystem - Analysis



Decrypt a single ciphertext

Exploit properties of decryption

Extract private key

Exploit properties of decryption or key generation

Application to Code-Based Cryptography

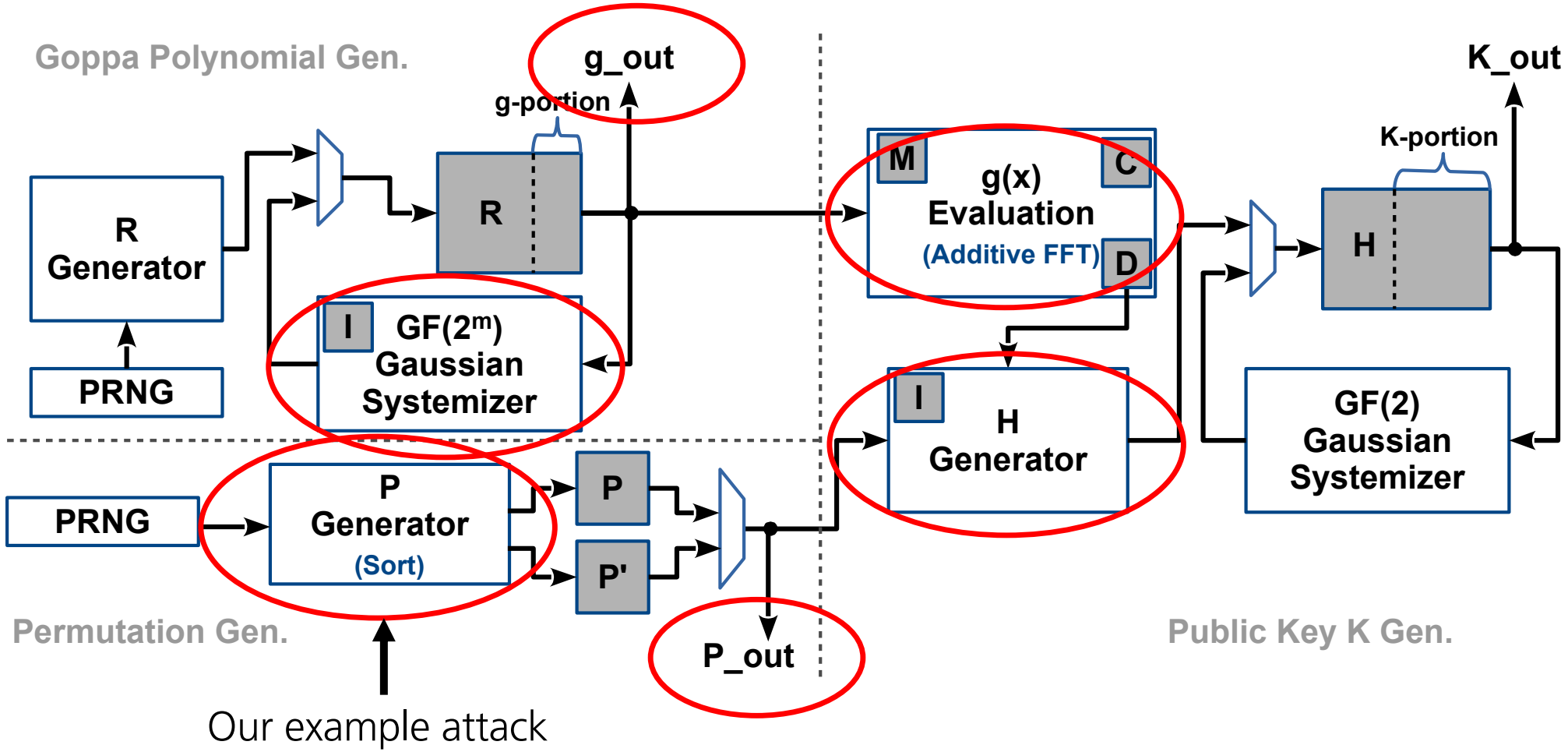
Niederreiter Cryptosystem - Analysis

Why attack the key generation?

- Private key is large
- Private key can be regenerated from a seed
- Many implementations will regenerate the private key on demand, e.g. on power up
- Power or EM trace can be recorded many times without effort (for noise reduction)

Application to Code-Based Cryptography

Niederreiter Cryptosystem - Key Generation



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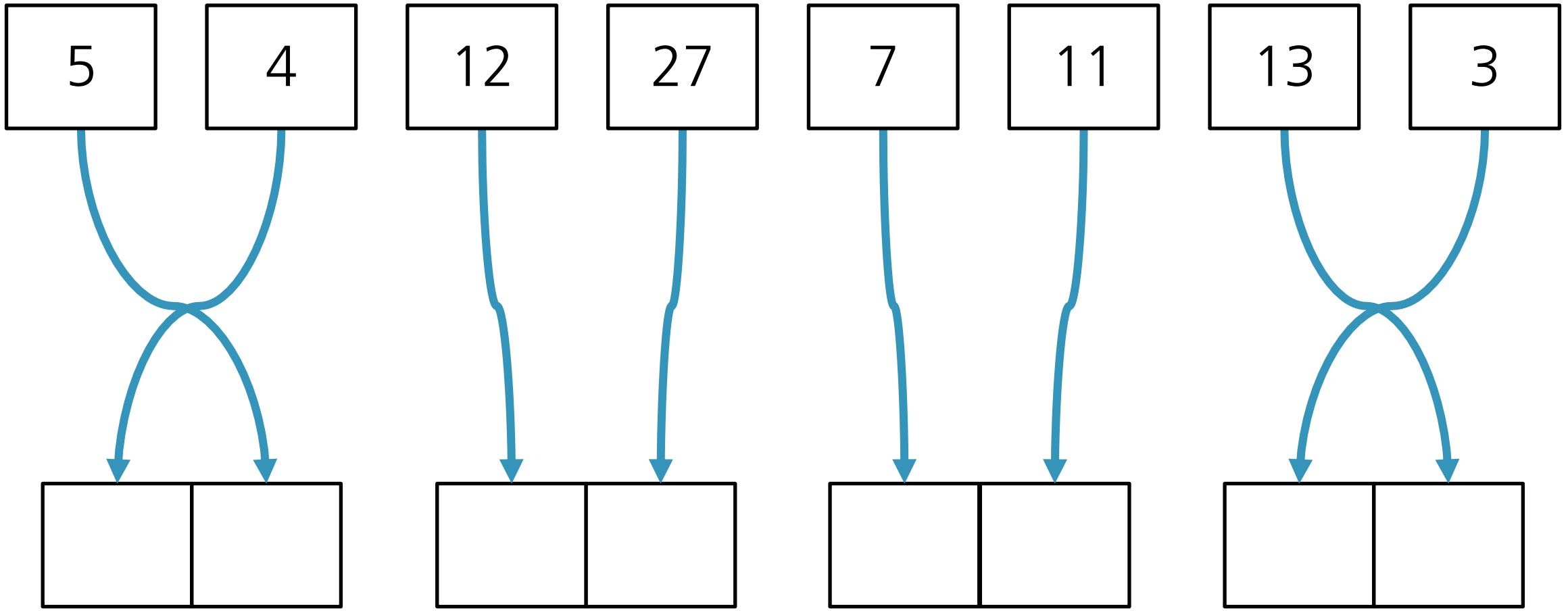
Demonstration on Merge Sort

Attack on Key Generation

Merge Sort



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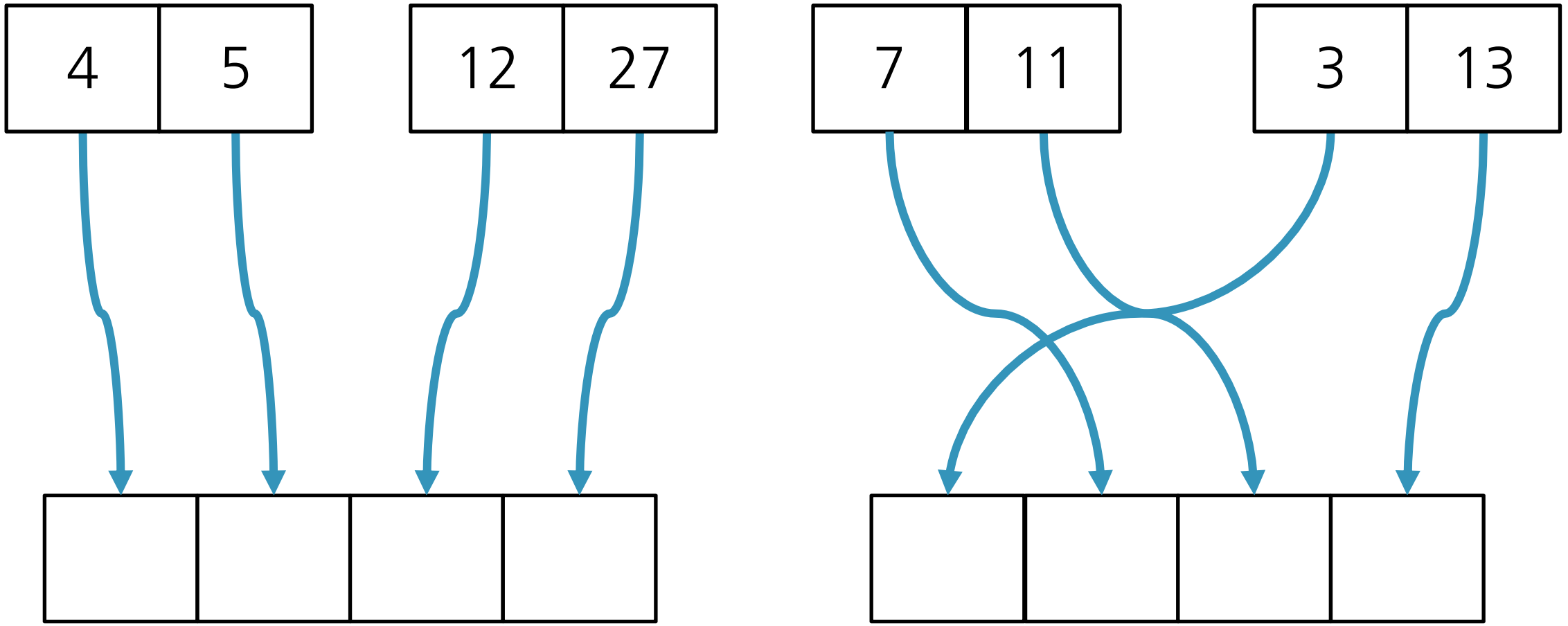
Attack on Key Generation

Merge Sort



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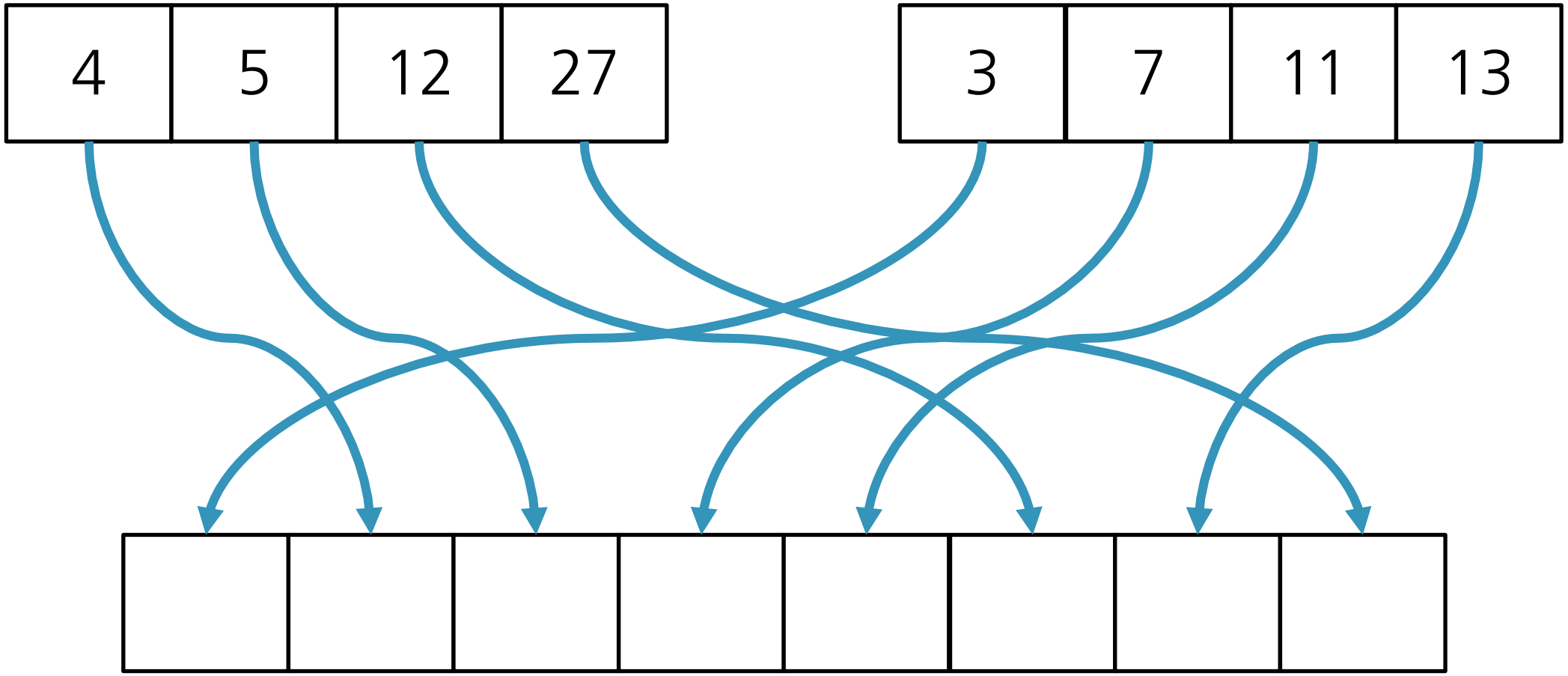
Attack on Key Generation

Merge Sort



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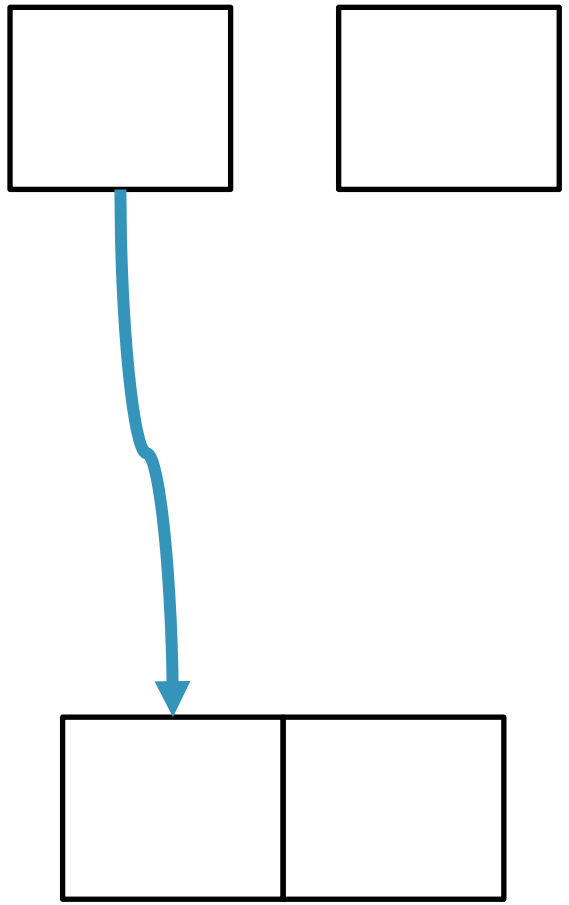
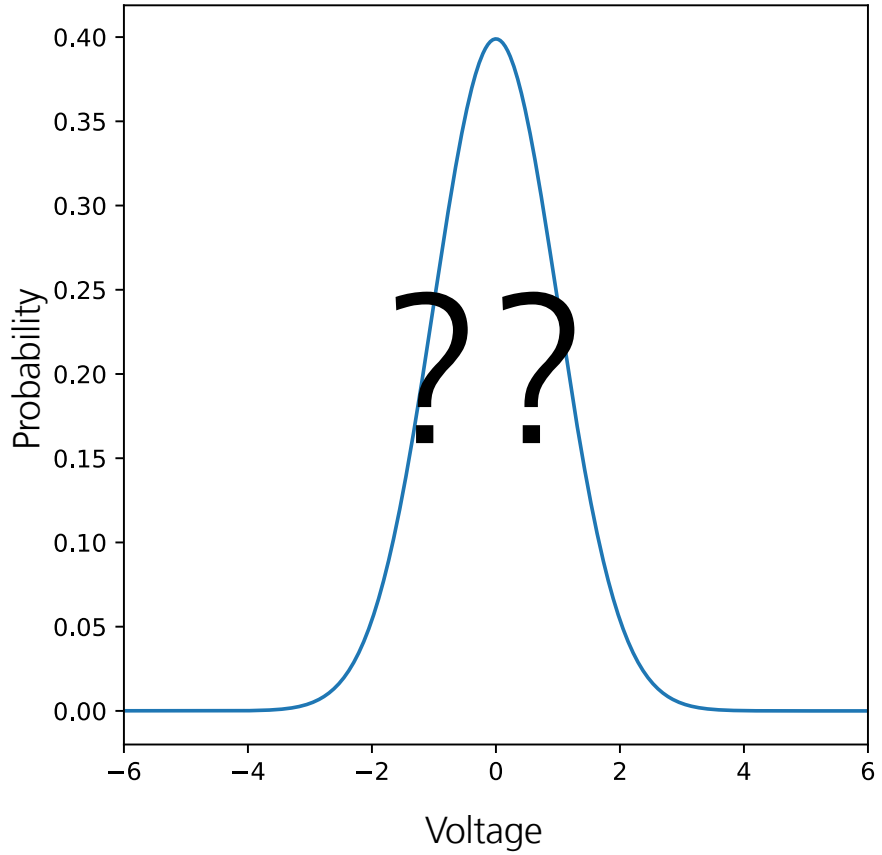
Attack on Key Generation

Merge Sort – Attack Concept



Assumption for “left” (blue)



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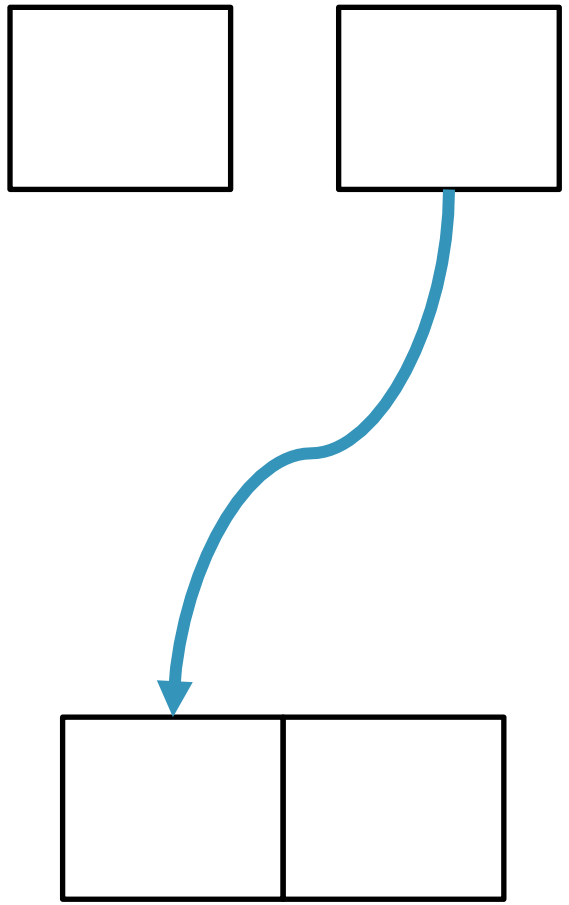
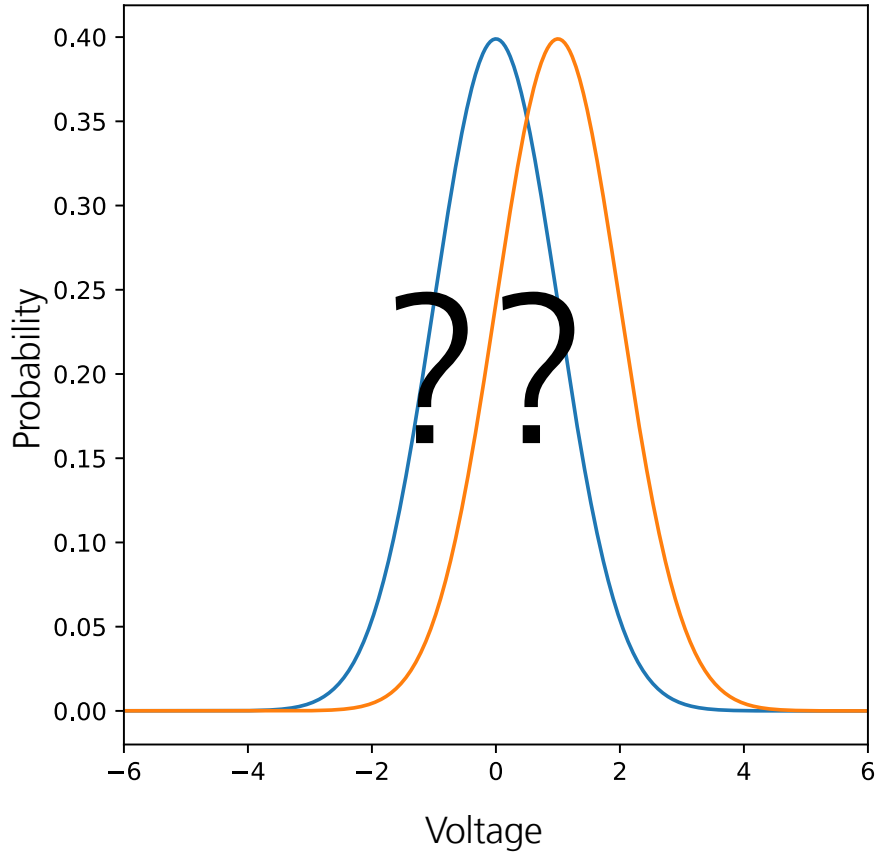
Attack on Key Generation

Merge Sort – Attack Concept



Assumption for “right” (orange)



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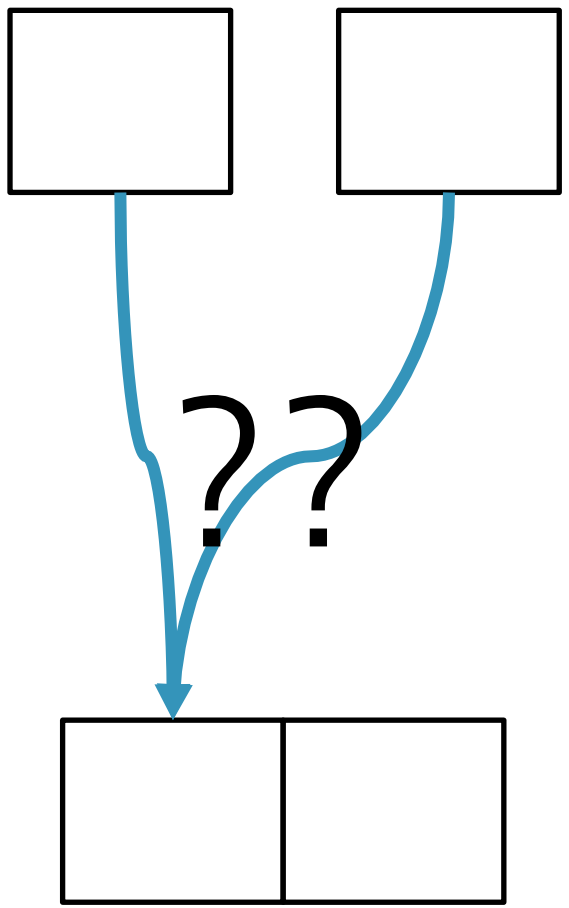
Attack on Key Generation

Merge Sort – Profiling



Remember: We are generating the same key every the time!

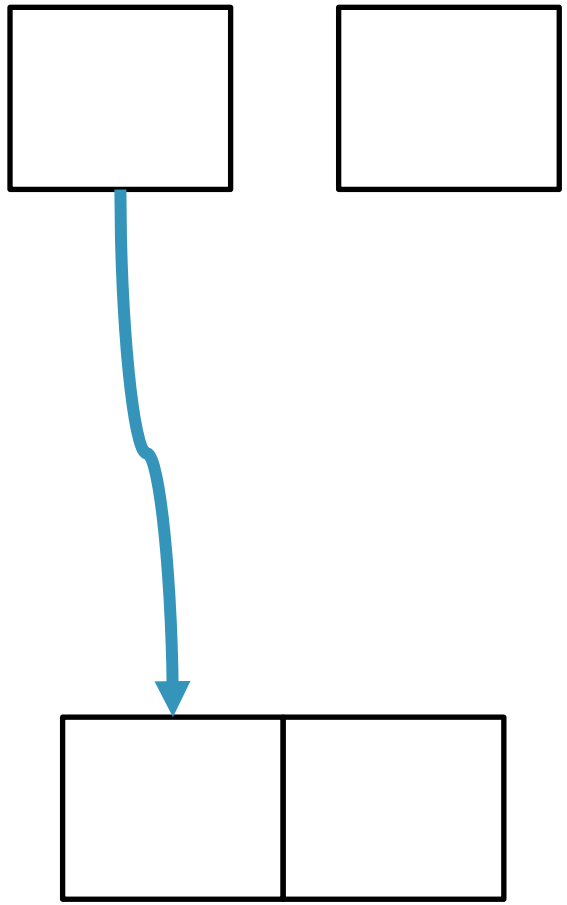
Problem: How to differentiate between “left” and “right” in a single trace?

Unknown pattern of power consumption for “left” and “right”.

Unknown position of the interesting points in a power/EM trace.

Attack on Key Generation

Merge Sort – Profiling

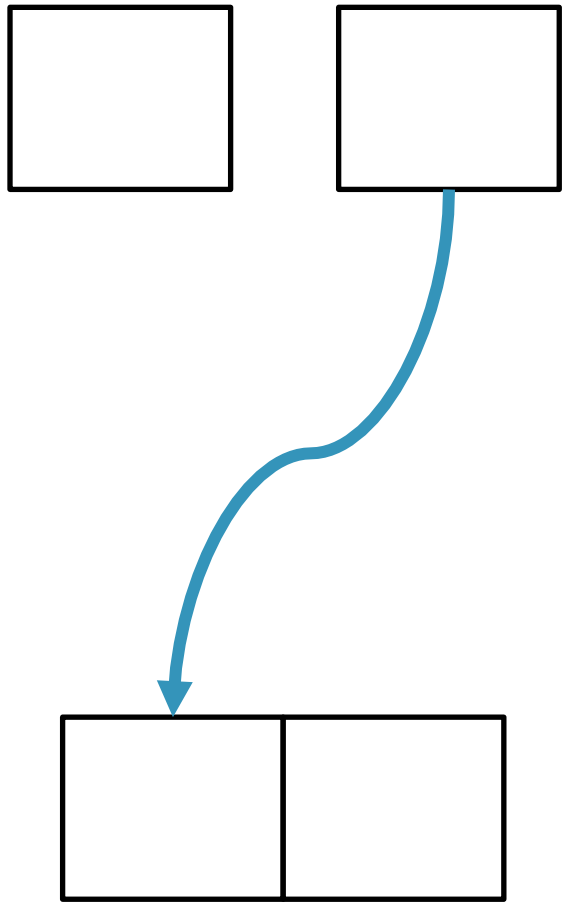


Profiling assumption:
Attacker is able to set the seed

Measure selection “left”
with different seeds.

Attack on Key Generation

Merge Sort – Profiling



Profiling assumption:
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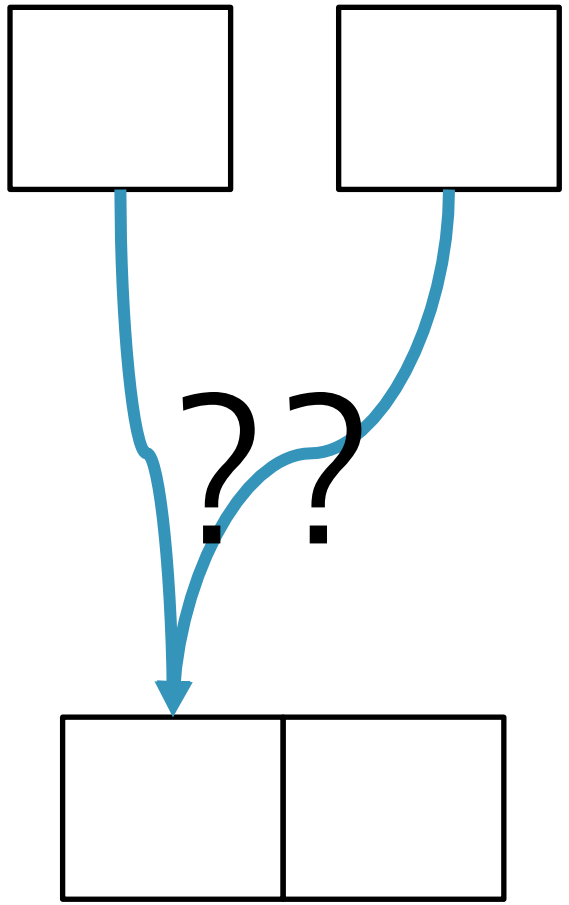
Attack on Key Generation

Merge Sort – Profiling

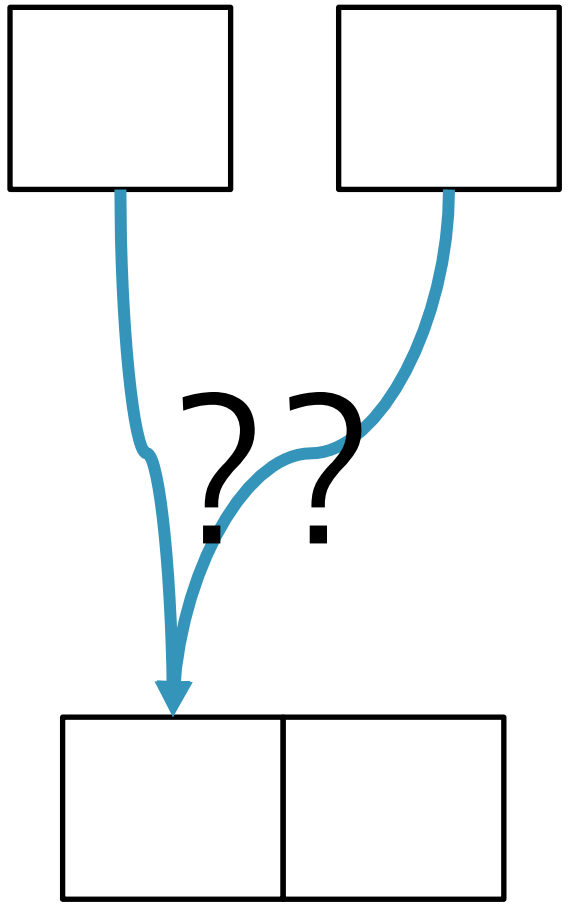


Statistical Leakage Detection:

Identifies the points of interest in the trace

Attack on Key Generation

Merge Sort – Profiling



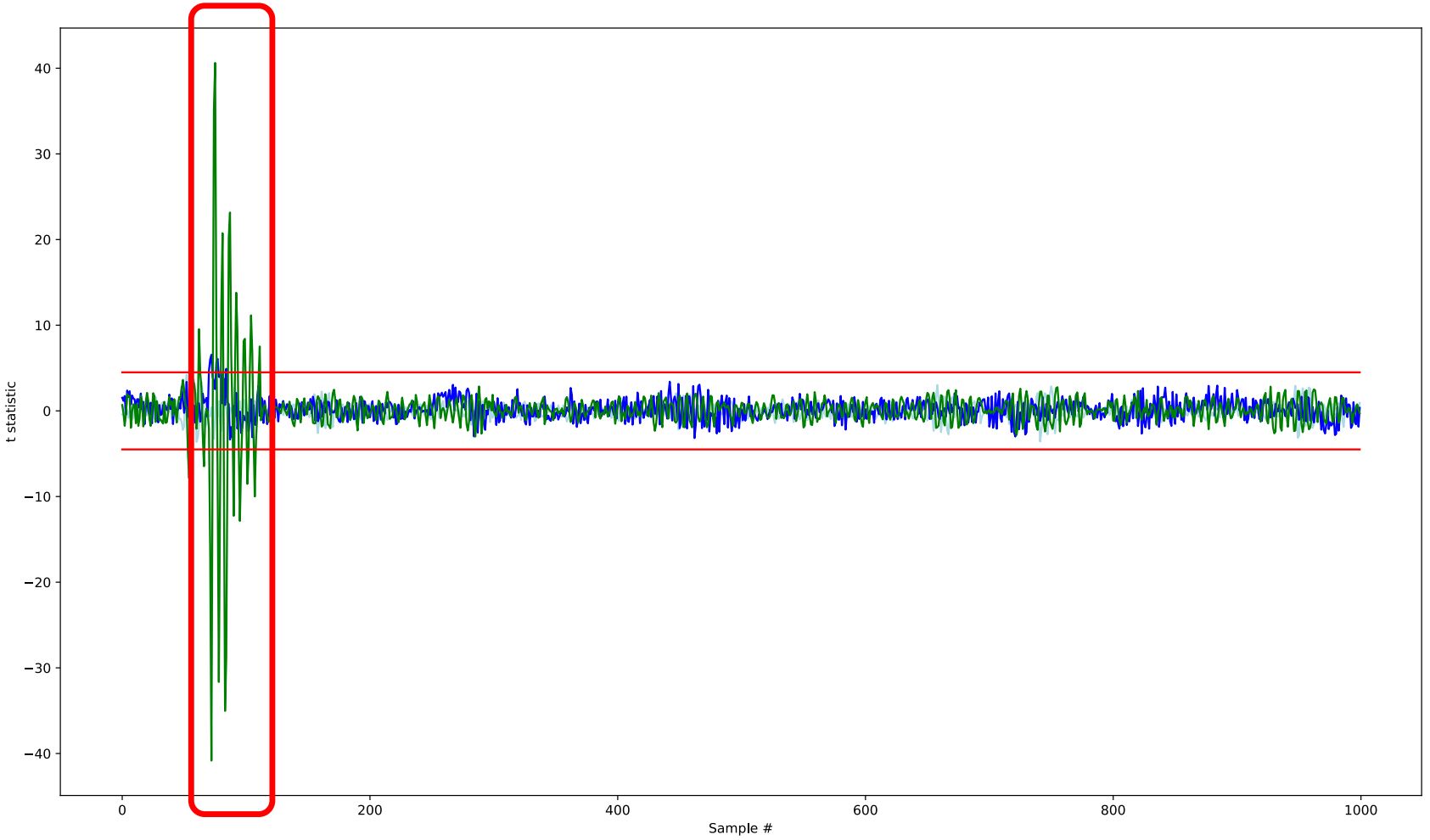
Welch's t-test:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}}$$

Significant leakage, when |t| > 4.5

Attack on Key Generation

Merge Sort – Profiling



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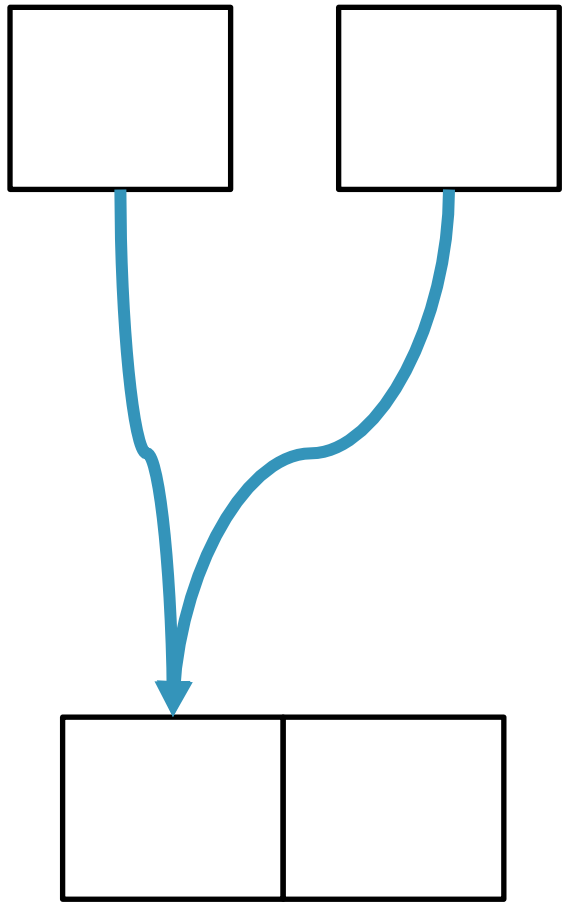
Attack on Key Generation

Merge Sort – Profiling

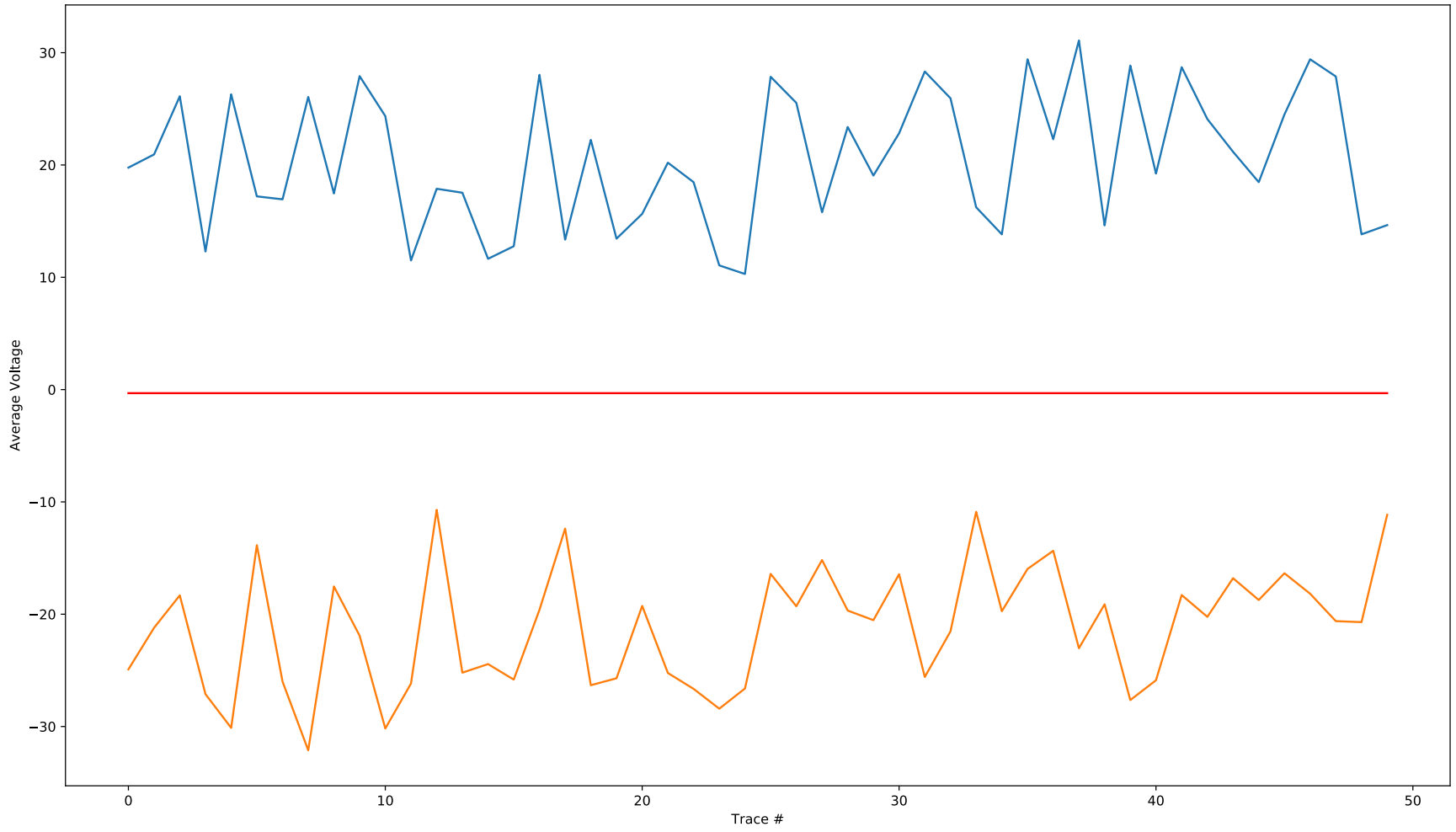


Generate Profiling Information

Simple model:
Global weighted threshold

Attack on Key Generation

Merge Sort – Profiling



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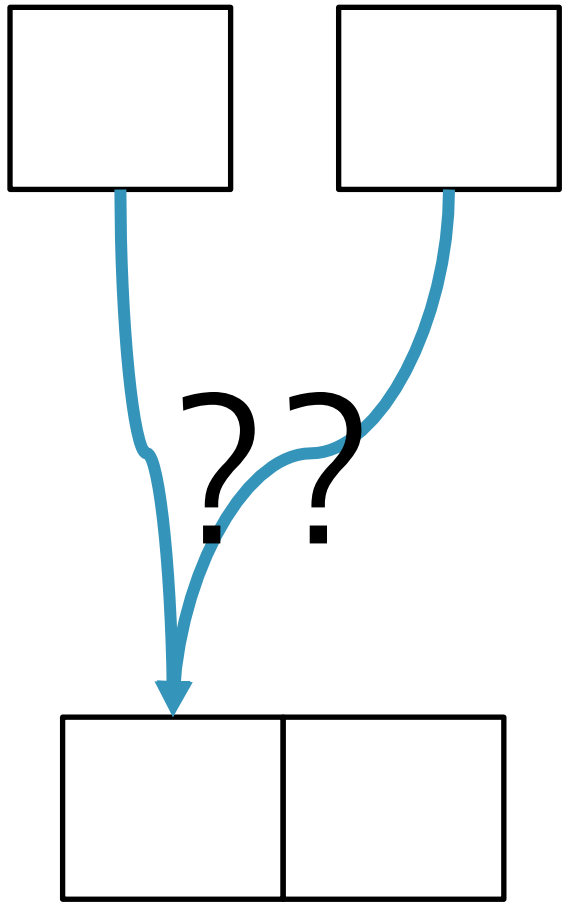
Attack on Key Generation

Merge Sort – Attack Phase



Record many traces with secret key

Average traces (noise reduction)

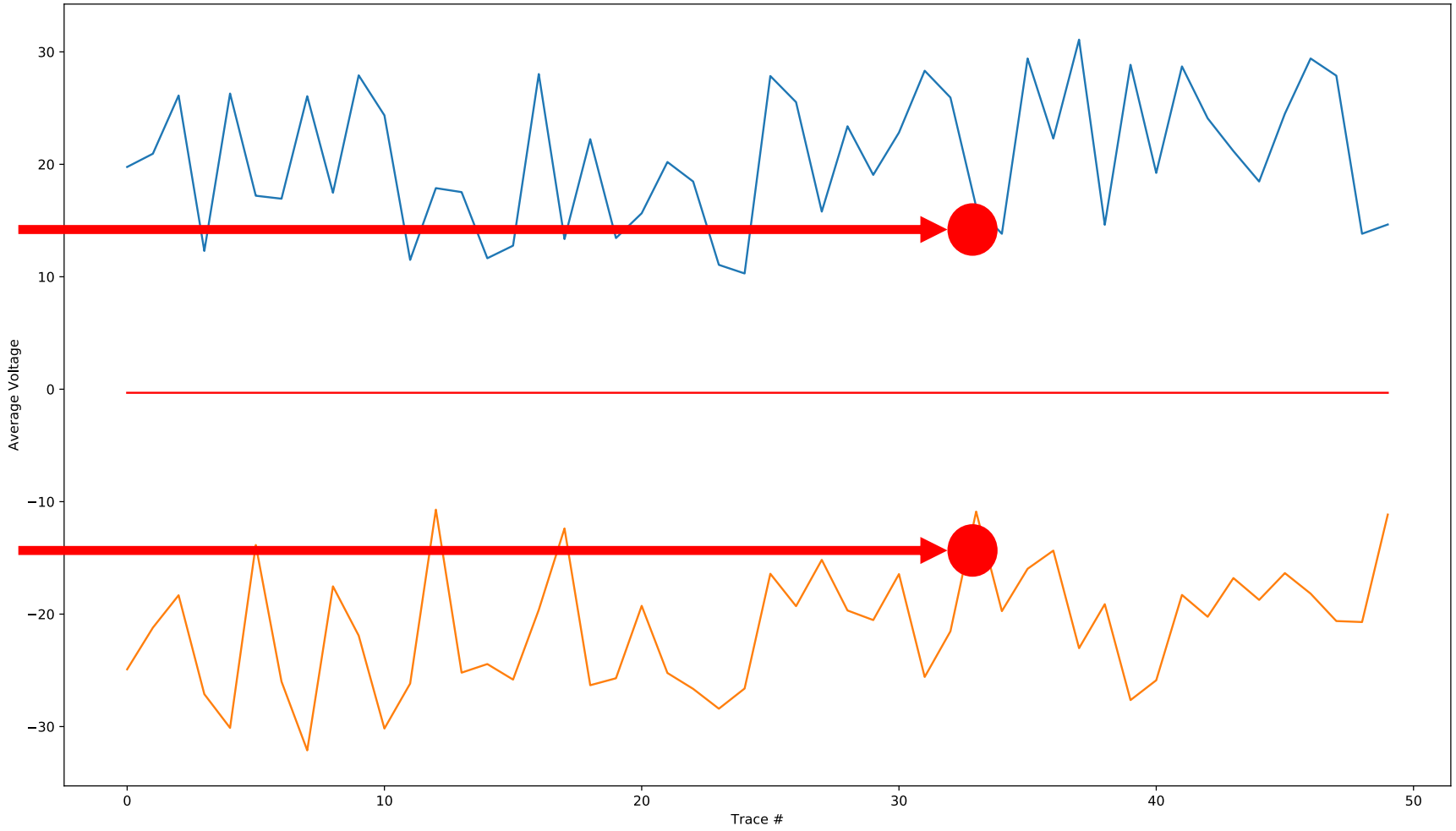
Compute weighted mean of points of interest

Attack on Key Generation

Merge Sort – Attack

"left"

"right"



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Countermeasures

Attack on Key Generation

Countermeasures – Hiding the Key

Randomize data?

Trivial randomization:

- Changes permutation or
- Exhibits same behavior

➔ Doesn't work!

Attack on Key Generation

Countermeasures – Hiding the Key

Randomize data?

Advanced idea:

- Generate different data
- Leading to same permutation, but
- Different “left”-”right” selection behavior

Computationally very hard ➔ Doesn’t work!

Attack on Key Generation

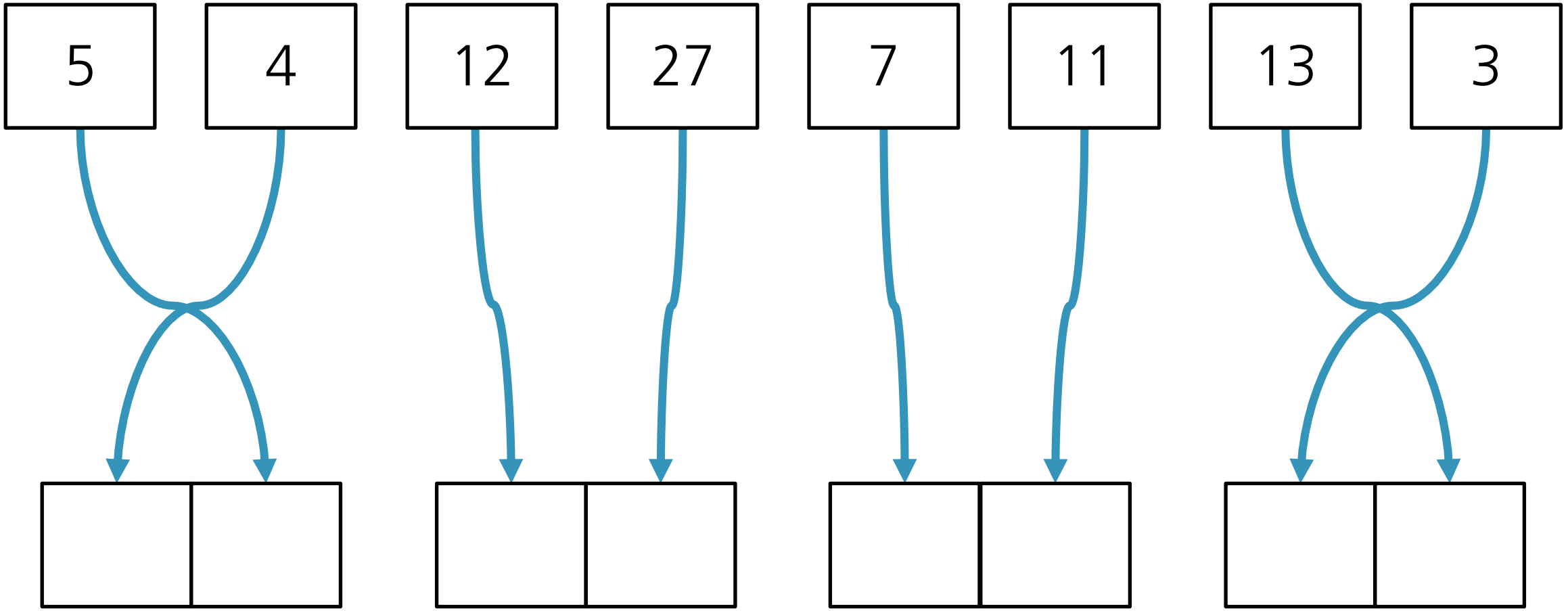
Countermeasures – Hiding the Key

Disturb signal or randomize execution

- Add clock jitter
- Add noise sources
- Shuffling of operations for each key generation

Attack on Key Generation

Countermeasures – Shuffling



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Attack on Key Generation

Countermeasures – Shuffling

For merge sort, there are 8192! possible permutations for the first layer alone.

SNR can be significantly reduced.

Thank you for your attention!

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